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Stretch Shortening Cycle in Childhood

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Abstract

The examination of stretch shortening cycle (SSC) in children became an interesting topic for research during the past years as it provides an important insight into the functioning of the neuromuscular system. This paper presents several studies related to children and their ability to jump. The reasons for children doing more poorly in jumping as compared to adults are complex and multi-factorial. Current data illustrate differences in biomechanical patterns, in the elicited ground reaction forces and in the neuromuscular activation obtained by electromyography (EMG) during jumping. Most of the findings converge towards the idea that children adopt a less mature and more inefficient technique which has some common characteristics with the "absorbing type" jump of adult jumpers displaying poor technique. The conclusion is that the children's deficit in jumping can be attributed to differences in technique that lead to less efficient stiffness regulation and in some cases, such as drop jumps, derive less benefit from the SSC mechanism.

Keywords: children; stretch shortening cycle; jump; kinematics; electromyography; reflex

1. Introduction

Our understanding regarding the function of the neuromuscular system in humans has increased significantly during the past decades. This is mainly due to the focused research dedicated on this field, and to the new methods used as tools to get an insight into the functions and mechanisms that derive from it. Some of these methods have helped us to understand better the neuromuscular system during the developmental ages. Regarding voluntary movements, it seems that children do not behave as "adult miniatures" but have sometimes their own movement patterns and strategies to achieve the same goal. The interest for research in children and the function of their neuromuscular system has increased during the past years, because of the increased participation in competitive, educational, and recreational sport activities. This was a consequence of the establishment of the exercise benefits in children, knowing that they tend to be more sedentary, mainly due to environmental reasons.

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The aim of this paper is to better understand the function of the neuromuscular system of children during activities involving the stretch shortening cycle (SSC). The studies presented will be mainly focused on the task of jumping. It will give a detailed description of the children's behavior which can help us understand how their neuromuscular system works, in order to improve its function.

1.1. Stretch shortening cycle

SSC consists of a rapid eccentric contraction followed immediately by a concentric one on the same muscle group (Norman and Komi, 1979). SSC is involved in many daily and sport tasks such as gait, running, hoping and jumping. Actually any movement that has a quick succession of eccentric and concentric contractions includes the phenomenon of SSC. Furthermore, plyometric training uses multiple drills that are based on the function of the SSC and consists a basic tool for strength and conditioning in order to improve jump height and explosiveness.

At least five different mechanisms may contribute to the force output potentiation during SSC (Harrison and Gaffney, 2001). Although it is beyond the scope of this paper to analyze them, it is important to note that the nature of the contractions during SSC has been recently questioned with the help of animal and human ultrasound studies (Hoffrén, Ishikawa and Komi, 2007; Griffiths, 1991), showing that muscle fibers can be shortened when the muscle group is stretched. Therefore, the above definition of SSC holds for the muscle tendon unit (MTU) and not for the muscle per se.

The fact that more force is produced when the muscle is initially stretched has been described by Cavagna et al. (1968). SSC is proposed as an economical way to produce forces using the elastic energy of the MTU (Gollhofer et al., 1984). Furthermore, there is a neural component, the stretch reflex, which is initiated during the lengthening movement. Stretch reflex is assumed to enhance muscle activation, and plays an important role in regulating the MTU stiffness or the joint stiffness of the system in general (Sinkjær et al., 1988). According to the literature, stiffness regulation is a very crucial property and determines the power output during various tasks. There are studies showing that a compliant MTU is responsible for the performance deficit (Hoffrén, Ishikawa and Komi, 2007), whereas other authors support a benefit in performance with a more compliant MTU (Walshe and Wilson, 1997). The current and most plausible aspect on this issue is that there is an optimal stiffness that could enhance performance, and below or above this optimum, performance decreases (Arampatzis et al., 200).

Active MTU stiffness, i.e. stiffness that is dynamically changed by modulations in the neural output, can be regulated by two mechanisms: the stretch reflex and the muscle activation. The stretch reflex gain is controlled through the activation of the γ-motoneurones, the level of Ia afferent pre-synaptic inhibition and the excitability of the α-motoneurones. Regarding muscle activation, stiffness is regulated by the level of co-activation of the agonist and antagonist muscles. More specifically in vertical jumps, stiffness can be regulated by controlling the activation of the muscles that are absorbing power. For drop jumps, muscle activation amplitude and duration before the contact with the ground (pre-activation) and during the braking phase can be an important factor for stiffness regulation (Horita et al., 2002).

1.2. Jump types

The task of jumping is used frequently in the examination of SSC. The most commonly referred jump types in the literature are the following:

- Squat jump: jumping as high as possible from a half-squat position. In the initial position knees are flexed at 90 degrees. No countermovement is allowed. Squat jumps have three phases: the propulsion, the flight and the landing phase. Although no countermovement is actually performed, even during squat jump the presence of the SSC (in a small extend) is inevitable (Bobbert and Casius, 2005).

- Countermovement jump: jumping as high as possible from a standing position. The trial starts with a downward movement by flexing the lower limbs and making a countermovement of the whole body. After lowering the center of mass to a certain point, the lower limbs are extended by performing a rapid concentric contraction. Countermovement jumps consist of four phases: the braking, the propulsion, the flight and the landing phase.
- Drop jump: landing from a pre-defined height and jumping as high as possible immediately after touching the ground. The subject leaves a step with the one foot and the other follows leaving the body in free fall. After touching the ground the subject jumps as high as possible. Drop jumps have five phases: the pre-contact, the braking, the propulsion, the flight and the landing phase.

A comparison of the above mentioned jump types offers a unique possibility for the examination of the SSC. More specifically, different jump types use in different extent the SSC; squat jump relies minimally on the SSC and countermovement jump shows better performance than the squat jump, a fact that is at least partially attributed to the contribution of SSC. The increase in performance due to the contribution of the SSC will be called “SSC gain” for the needs of the current paper.

Relative to countermovement jumps, during drop jumps the momentum of the body induces a more rapid stretch of the muscles when touching the ground. This effect increases as drop height increases which implies that the drop height determines the amount of stretch. That, consequently, will influence the amount of the stored elastic energy and the stretch reflex output.

Another interesting issue rises from the research of landings, which involves only the absorption of momentum from the musculoskeletal components of the lower extremities. In this case the mechanism of the SSC is not involved at all because no stored energy is returned by the shortening of the MTU. Therefore, when comparing the behaviour of the drop jump braking phase and the braking phase of landing, we have two similar situations with at least one major difference: during drop jumps stiffness regulation in landing is controlled by muscle activation and reflex response, but during landing the contribution of reflexes on stiffness is limited (Leukel et al., 2008). This is probably because during drop jumps increased amount of power and stiffness is required to achieve higher jump height during the subsequent concentric contraction, whereas landing requires a more compliant system to absorb the momentum safely.

2. Jumping during the developmental ages

As mentioned above, children use jumps in their everyday life, as well as in their training or competition when they are involved in a sport activity. In the following paragraphs there is a description of different jump types in children compared with adults, in order to understand the reasons for their performance deficit.

Comparing the performance of squat jump and countermovement jump during development (11 to 16 years old), younger children demonstrate more SSC gain than the older ones, when calculating the difference between countermovement and squat jump height (Bobbert and Casius, 2005). This interesting finding gives evidence that younger children are more able to benefit from the SSC. However, it is reasonable to argue that this increase in SSC gain could be attributed to a much more reduced performance in squat jump of younger children. This is also supported by the greater variability observed in children’s squat jump performance compared to adults [2]. Furthermore, the reduced performance in squat jump in children is supported by their decreased muscle length and their reduced contraction velocity of their muscles (Bobbert and Casius, 2005).

There are several differences between children and adults that could influence their performance in jumping. Except the obvious deficit in muscle strength in absolute values, it has been questioned whether children activate their motoneurones on the same extent and with the same strategy (Grosset et al., 2008). More specifically, electromyogram (EMG) is lower in children during maximal voluntary contraction, whereas the relative EMG activity during submaximal contractions is higher compared to men (Grosset et al., 2008). This interesting finding indicates that children vary their neural activation differently and seemingly sub-optimally compared to adults and therefore it is expected for them to be less efficient in challenging and complex tasks, such as jumping.

From a mechanical point of view, children have more compliant MTU than adults (Kubo et al., 2001; Lambertz et al.,2003). This implies that the energy storage and transfer could be different and therefore, different activation patterns might be required for an optimal performance. In general, it is expected that a more compliant MTU will be able to store more elastic energy (Kubo et al., 2001). It seems however that although the energy might be stored in the MTU of children, they are not able to return this energy to contribute to higher performance (Lazaridis et al., 2010). The possible reasons and mechanisms are analyzed below.

2.1. SSC gain in children

A comparison between children and adults in squat jumps and countermovement jumps has shown that both groups are able to utilize the benefits of the SSC (Harrison and Gaffney, 2001). According to earlier studies, children, as compared to adults, showed even greater SSC gain when expressed as a percentage of squat jump performance (Harrison and Gaffney, 2001; Bosco and Komi, 1980). Thus, it seems that SSC in children can be used effectively.

Drop jump performance in adults has a typical behavior. In general, jump height is greater than the countermovement jump (Bobbert et al., 1987; Voight et al., 1995) and it increases with increasing drop height up to a certain level, ranging from 30 to 40 cm (Voight et al., 1995; Asmussen and Bonde-Petersen, 1974). Further increase in drop height induces a decrement in performance (Walshe and Wilson, 1997; Bobbert et al., 1987). The possible mechanism for this decrease is probably protective and neural in nature (Walshe and Wilson, 1997; Leukel et al., 2008). In children, there is no gain observed during drop jumps within a drop height range of 10 to 50 cm (Lazaridis et al., 2013; Bassa et al., 2011). Furthermore, trained children performed better than untrained peers in squat and countermovement jump but did not show any SSC gain in drop jumps relative to the performance in squat jumps when dropping from various heights (Bassa et al., 2011)). This indicates that children are not able to use effectively the SSC during drop jumps.

2.2. Biomechanical properties during jumping in children

There is only limited research on the biomechanical properties of jumps in children. Most of the studies have focused on the jumping technique by evaluating parameters related to the anterior cruciate ligament (ACL) injury (Barber-Westin et al., 2006). Such parameters are the knee angle and knee joint moments when touching the ground during drop jumps. Since the ACL injury prevalence is more frequent in girls than in boys, these studies focused on between-sex comparisons of children. The main outcome was the documentation of a more knee valgus position during landing in girls compared to boys which could induce complications in loading the knee disproportionally.

A recent study comparing drop jumps between children and adults showed that children flex their hips more during the braking phase (Lazaridis et al., 2010). Furthermore, when comparing trained and untrained children (recreational active and gymnasts) a similar pattern was observed (McNitt-Gray, 1991). According to these authors, the reason for the augmented hip flexion during landing from drop jump could be purely mechanical, which means that the hip extensor muscles are not able to counteract the momentum of the body.

Furthermore, during drop jump children land on the ground with their knees in a less flexed position, despite the fact that they flex their knees more at the end of the braking phase (Lazaridis et al., 2010). This has several implications. Less flexed position during landing is linked to less torque production (Aagaard et al., 2000), which gives a disadvantage to children compared to adults not due to their difference in muscle mass but due to the positioning of their legs. This implies that children are less capable to withstand high ground reaction force

impacts during landing. This missing attribute of children might be explained by the fact that they are less capable in predicting an event (Assaiante and Amblard, 1996), i.e. the contact of their feet with the ground.
One of the consequences of landing on the ground with extended knees shown in children is that they produce higher peak vertical ground reaction forces (normalized to their body weight) compared to adults, when landing from drop jump (Lazaridis et al., 2010). These higher ground reaction forces could also possibly explain the longer contact time on the ground (braking phase duration) shown by the children, because they have to distribute this load over a longer period. Nonetheless, longer contact time could result in a non-optimal transition from the lengthening to the shortening phase of the SSC (Bosco and Komi, 1980). Previous studies have shown that during the maturation process children become more able to regulate their ground reaction forces when landing (McNair et al., 2000). Considering the above it seems that the shock absorption mechanism in children is deficient and this could raise long-term concerns for injury risk.

2.3. Neuromuscular properties of jumping in children

According to a recent study, prepubescent boys showed lower and shorter preactivation in drop jumps than men (Lazaridis et al., 2010). Furthermore, soleus and medial gastrocnemius were less active in boys during the braking and propulsion phase, and their short latency reflex of the same muscle was reduced as well compared to adult males. Interestingly, similar neuromuscular deficit has been observed in elderly people (Hoffrén et al., 2007). The above results indicate that children were not able to regulate (increase) their joint stiffness when performing drop jumps. It has been speculated that the reduced stretch reflex in children occurs due to their less sensitive muscle spindles (Grosset, 2007). Furthermore, children compared to adults show higher knee angular velocities during the braking phase (Lazaridis et al., 2010) and this induces higher stretching velocities which in turn could be an inhibiting factor for the activation of the muscle (Voight et al., 1995).

The failure of children to regulate properly their stiffness is also supported by the fact that when landing they flex their knees more at the lowest point of the braking phase (Lazaridis et al., 2010). The lack of adaptability on neuromuscular level has been also shown by an EMG study comparing drop jumps from 20 and 40 cm in children and adults (Lazaridis et al., 2013). In this study, although adults adapted their neuromuscular system in terms of EMG when varying drop heights, children were unable to do so in a significant extent.

As mentioned above, men during landing in drop jumps have a more extended knee position compared to children. This could be also explained by their higher preactivation in terms of amplitude and duration (Lazaridis et al., 2010). According to Viitasalo et al. (1998), less experienced people show a delayed preactivation, and in our case, it seems that children behave as such. Although there are several other characteristics that describe a poor or a good jumper (Horita et al., 2002), it is tempting to suggest that children agree more with the profile of a poor jumper. The type of jump that these jumpers adopt has higher dampening properties (increased contact time, higher maximum knee flexion at the end of braking phase, decreased agonist preactivation and activation during the braking phase) and is called “absorbing” type.

Regarding the antagonistic co-activation which is counter-productive concerning the produced torque and power, but increases joint stiffness and is a protective element for the musculoskeletal system (Kellis, 1998), conflicting results are presented in the literature. In general it seems though that in tasks such as balance, walking and running children perform higher levels of antagonistic co-activation (Schmitz et al., 2002; Frost et al., 1997). Regarding jumping and more specifically drop jumps, children have higher level of antagonistic co-activation compared to men during the braking and propulsion phase (Lazaridis et al., 2010; Lazaridis et al., 2013). Furthermore, children fail to increase their co-activation when falling from higher heights in drop jump (Lazaridis et al., 2013) or when landing on an offset target (Russell et al., 2007). On the other hand there are indications that skillful children have less antagonist co-activation (Hamstra-Wright, 2006). Considering the above data regarding the agonist-antagonist co-activation, it is possible that motor learning and immature technique could be responsible for the performance deficit observed in children.

3. Conclusions and suggestions for future research

The inferiority of children in jumping compared to adults could be attributed to their less effective muscle activation and stiffness regulation throughout the whole SSC. Motor learning and maturation processes could play an important role on the above mentioned issues. Further research is required, and more particularly longitudinal studies, in order to elucidate the effects of different types of training (focused on the technique, strength, coordination etc) with various types and magnitudes of loading on the MTU. The effectiveness of such training programs during the developmental ages can be verified and established by evaluating changes on the SSC and human movement.

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